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Analysis of Removal Mechanism on Oxide CMP using Mixed Abrasive Slurry

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Mixed abrasive slurry (MAS) is one of the non-traditional slurries with more than two different sizes, shapes or materials of abrasives which are to improve a chemical mechanical polishing (CMP) performance such as a removal rate. This paper focuses on the MAS mixed with two different sized abrasives and controlled by mixing ratio. Hybrid effect of the MAS was investigated from the removal mechanism of the mixed abrasives on oxide film. Experiments have been implemented with a 4-inch wafer with silicon dioxide film and KOH-based colloidal silica slurries. The slurry has two different sizes, 30 nm and 70 nm, with concentration of 1~30 wt%. The effects of abrasive concentration and mixing ratio were investigated in the oxide CMP in order to achieve high removal rate. During the oxide CMP with the MAS, the contact condition of abrasives was changed by mixing ratio. Through the experiment, it could be seen that two-body and three-body abrasions occur in mixed abrasive slurry according to the particle concentration. Finally, we could see that the proper ratio to achieve high removal rate was 2:1 (D30:D70) since most of the abrasives were active in material removal and carried out two-body abrasion.

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1. Introduction

Chemical mechanical polishing (CMP) is a process of smoothing and planarizing wafer surfaces by using a combination of chemical reactions and mechanical forces.[1] Numerous parameters are involved in the material removal process, such as the type of abrasive, pressure on the wafer, relative velocity between the polishing pad and the wafer, slurry chemistry, polishing pad, and substrate characteristics.[2,3] The fundamentals of silicon dioxide (SiO_2) CMP are understood from various studies of glass polishing. The predominant mechanism responsible for SiO_2 removal is the mechanical abrasion followed by hydration of the SiO_2 surface in the presence of an alkaline slurry.[4,5] The hydrated layer is rapidly formed on the SiO_2 surface by the indentation of the silica particles against the SiO_2 film in the slurry.[6]

The CMP performance can be optimized by process parameters such as equipment and consumables (pad, backing film, and slurry). One of the critical consumables in the CMP process is a slurry typically containing both abrasives and chemicals acting together to planarize films. The conventional slurry consists of abrasive particles of the solid state suspended in a liquid state chemical solution.[7] Abrasives in the slurry transfer mechanical energy to the surface being polished and helps in their material removal. Through chemical and physical actions, the abrasive-liquid interactions play an important role in determining the optimum type, size, shape, and concentration of the abrasives.[8] The slurry designed for optimal performance should produce reasonable removal rates, acceptable polishing selectivity with respect to the underlying layer, low surface defects after polishing, and good slurry stability.[9] The techniques of friction force measurement are increasingly used for the control of material removal during CMP and in the studies carried out to understand the CMP mechanism, because CMP is a typical tribological process of removing thin films by sliding friction among the wafer, pad, and slurry.

This paper focuses on the mixed abrasive slurry (MAS) which is one of the non-traditional slurries with two different sized abrasives and controlled by mixing ratio, in order to improve the CMP removal rate (RR). The energy and the cost of process can be saved by using MAS in proper ratio because it can improve the efficiency of the process and, in turn, reduce the process time. Especially, hybrid effect of the MAS is investigated from the removal mechanism of two-body and three-body abrasions on oxide film.

Table 1 CMP slurries for experiments

Slurry	Mean (nm)	Viscosity (cps)	Specific gravity (g/cc)
D30	26.6	6.4	1.204
D70	67.4	2.61	1.197

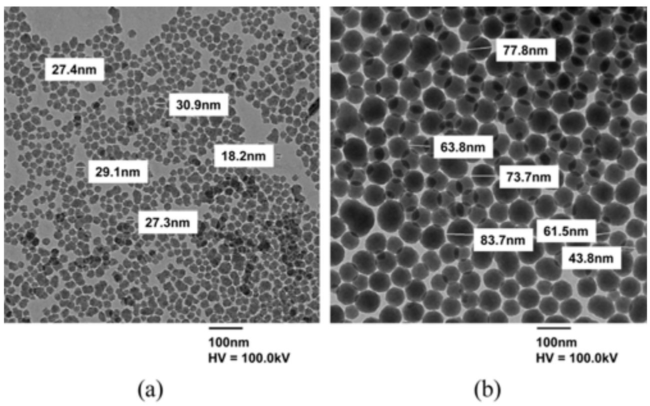

Fig. 1 TEM images of slurries; (a) D30, (b) D70

Table 2 Experimental conditions

Parameters	Conditions
Work material	1μm thick SiO_2 film on 4-inch wafer
Slurry	Colloidal silica slurry (KOH based, 30 wt%) D30, D70, and MAS
Pad	IC1000/SubaIV
Pressure	100~700 g/cm^2 (ref.; 500 g/cm^2)
Velocity	30~120 rpm (ref.; 60 rpm)
Slurry flow rate	150 mL/min
Process time	1 min

2. Experimental Conditions

1 μm thick SiO_2 film on 4 inch wafer was used in the experiment. Two types of KOH based colloidal silica slurries were prepared for the experiments, as shown in Table 1. The abrasive diameter was measured by a particle size analyzer (ELS-Z, Otsuka Electronics Co.). The mean particle diameters for the two slurries were 26.6 nm (D30) and 67.4 nm (D70) (Fig. 1). The pH of each slurries is 9.7 (20^{o}C). Before using the oxide CMP, all of the slurry was adjusted to pH 11 by KOH solution. The rotary-type CMP machine (POLI-400, G&P Technology, Korea) and an IC1000/SubaIV stacked pad (Nitta Haas Inc., Japan) were used. During CMP, ex-situ conditioning was done under a pressure of 120 g/cm^2 and velocities of 60 rpm for conditioner disk and 83 rpm for platen. After CMP for 1 min, the thickness of the SiO_2 film was measured using a reflectometer (K-MAC ST5030-SL, Korea). Removal rate of the SiO_2 film was measured at 21 points on each wafer with edge exclusion of 5 mm. Table 2 shows the experimental conditions.

To measure dynamic friction during oxide CMP, the piezoelectric quartz sensor (Kistler Type 9135B) was used. It had the utmost flat sensor which was circular with 24 mm external diameter and 3.5 mm height. It also had a maximum force of 42 kN, a sensitivity of -3.8 pC/N, and a dynamic signal range of ~75 kHz. As shown in Fig. 2, the force sensor was positioned on the back surface of the polishing head, and then the sensor was preloaded to obtain dynamic friction force with

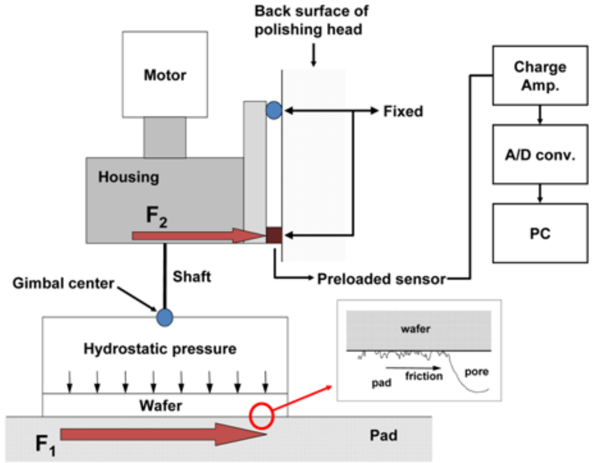

Fig. 2 Schematic of friction force monitoring system

sensitivity. When the sensor was loaded during CMP, it made an electrical charge proportional to the applied force. The voltage from the piezoelectric sensor was amplified through the charge amplifier (Kistler Type 5039A) because of the low output of electrical charge, and then transferred to a data acquisition board. Sensor voltage, which was induced by the repulsive force F_2, was calibrated according to a change in the friction force F_1 using loading parts with a load cell.

3. Results and Discussion

3.1 Characteristics of single abrasive slurry

Generally, the removal rate is well controlled under the Preston's equation[10] in the CMP process. This equation incorporates pressure (P) and relative velocity (V) as the main contributors to the removal rate (RR):

$$RR = kPV \tag{3-1}$$

First, we tried to investigate characteristics of the oxide CMP using single abrasive slurry, and the dependency of Preston's equation on the mechanical factors. The result was that the RR increased linearly according to the increase of pressure (Fig. 3) and velocity (Fig. 4) which was well matched with Preston's equation.

Fig. 5 shows the removal rate according to the abrasive concentrations of two slurries. The removal rate was proportional to the abrasive concentration in general CMP using silica-based slurry. Through the results, the number of abrasive particles played an important role in the removal of oxide film.[11,12]

The coefficient of friction (COF) was investigated in order to understand the effect of friction force on wear characteristics of the oxide film versus the abrasive concentration of two slurries, as shown in Fig. 6. The COF was very low, 0.003_{D30} and 0.009_{D70}, during the oxide CMP using 1 wt% of each slurry. As the silica abrasive concentration increased from 1 to 30 wt%, the COF increased to the transition point of 10~15 wt% abrasive concentration. The maximum COF at the transition point was 0.054_{D30} and 0.069_{D70}. After the transition point, the COF gradually decreased to 0.038_{D30} and 0.051_{D70}.

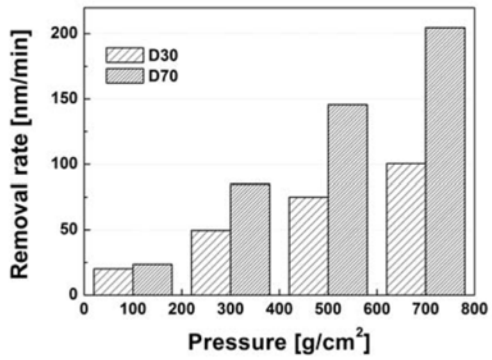

Fig. 3 Removal rate as a function of pressure

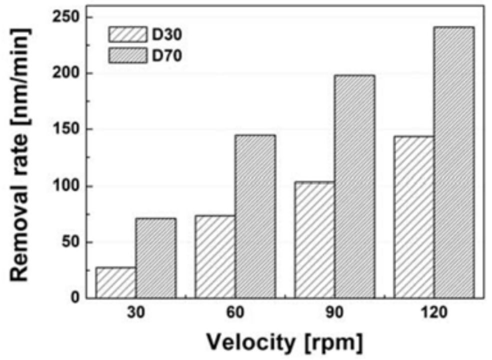

Fig. 4 Removal rate as a function of velocity

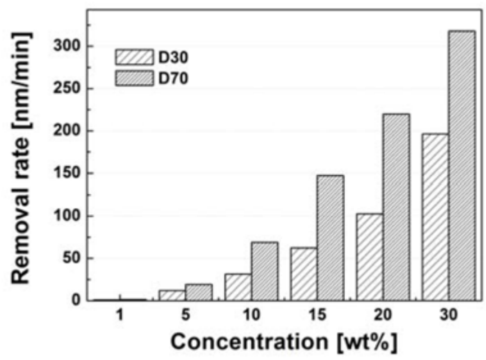

Fig. 5 Removal rate as a function of abrasive concentration

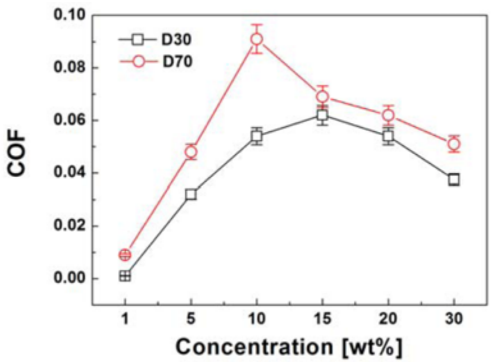

Fig. 6 Coefficient of friction as a function of abrasive concentration

Based on the results of the removal rate and COF with respect to the abrasive concentration in slurries, the presence of abrasive in both slurries raised the friction force, which is correlated with the wear amount of the oxide surface. The friction force in CMP with 1wt% concentration slurry was much lower than those of other slurries because the oxide wafer slid against polyurethane pad asperities with low indenting and plowing of abrasives on the oxide wafer surfaces. The friction force between the wafer and pad became higher in CMP according to higher concentration of abrasives, and it could then lead to higher removal rate. Accordingly, this result can be estimated by the concept of stability of the friction force according to the abrasive concentration in slurry. The stability means that the shear stress at the interface between the wafer and pad gradually decreases or becomes steady according to the number of abrasive particles, because of the wear behavior such as two-body and three-body abrasions by abrasive particles.[13]

3.2 Effect of mixed abrasive slurry

Fig. 7 shows the removal rate and COF according to the types of MAS. The total abrasive concentration is 30 wt% and each type of the MAS has different mixing ratios of 1:1 (15 wt%:15 wt%), 1:2 (10 wt%: 20 wt%) and 2:1 (20 wt%:10 wt%) for MAS_A, MAS_B and MAS_C, respectively. As the result, the removal rate and COF of MAS_C was the highest value, followed by MAS_A and MAS_B. Fig. 8(a) shows the contact condition of mixed lubrication, in which the wafer is pressed against the pad asperities with active abrasive particles in the oxide CMP

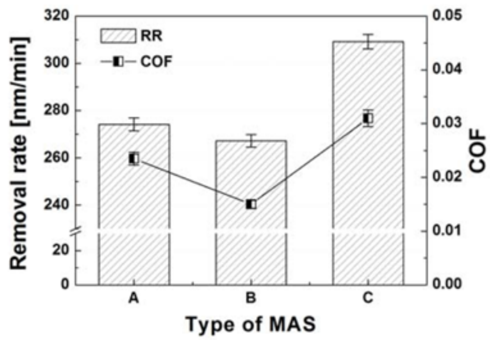

Fig. 7 Removal rate and coefficient of friction as types of MAS

process. The SiO_2 surface is polished by two-body abrasion of sliding abrasive, which is induced by strong elastic contact force between the abrasive particles and pad asperities.[13-15] The abrasive grains in the three-body case spend approximately 90% of the time for rolling, thus producing no abrasive wear particles, and only 10% of the time is spent for sliding and removing the surfaces. Inactive abrasive particles do not participate to the CMP.

The contact area of wafer, abrasive particles and pad is described in Fig. 8(b), (c) and (d) respectively using MAS_A, MAS_B and MAS_C. When the mixing ratio is 1:1, some of the D30 abrasive particles have three-body abrasion due to the decrease of the force acting on a single abrasive particle, as shown in Fig. 8(b). In case of the increased D70 abrasives

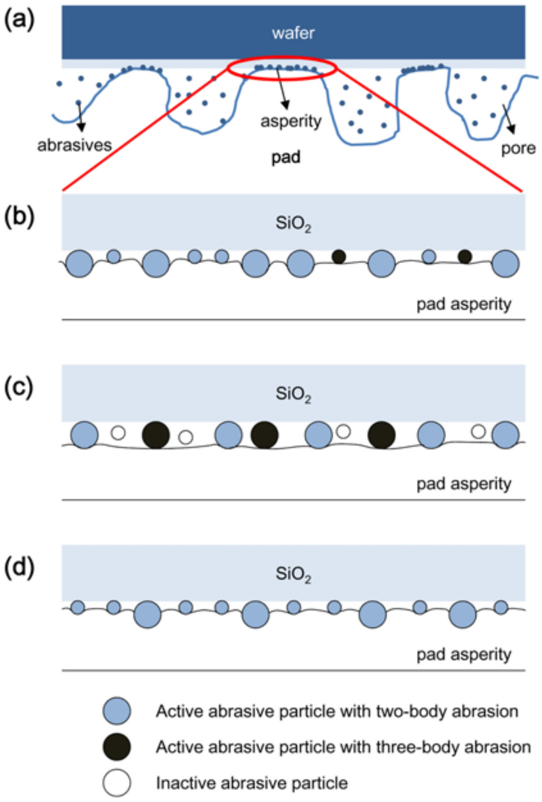

Fig. 8 Schematic of contact among wafer, abrasive and pad in oxide CMP process; (a) microscopic contact, (b) contact at MAS_A, (c) contact at MAS_B and (d) contact at MAS_C

(Fig. 8(c)), the pad deformation caused by active abrasive particles on the pad asperity decreases with the increase in abrasive concentration of D70, and then the SiO_2 surface on the wafer is removed by the low elastic contact force. Therefore, some of the D70 abrasive particles have three-body abrasion and the D30 abrasive particles can be inactive in material removal.[13,16] Thus, the removal rate and COF of MAS_B was lower than those of MAS_A. Finally, Fig. 8(d) (2:1) shows the two-body abrasion and inactive abrasive particles are not present due to the proper transform of the pad. Finally, the MAS_C can yield the highest removal rate and COF among three mixing ratio conditions.

4. Conclusions

This paper was studied on the mixed abrasive slurry (MAS) which is one of the non-traditional slurries with two different sized abrasives and controlled by mixing ratio, in order to improve the CMP removal rate. Especially, hybrid effect of the MAS was investigated from the removal mechanism of two-body and three-body abrasions on oxide film.

The removal rate was increased linearly according to the increase of pressure and velocity which was well matched with Preston's equation. The removal rate was proportional to the abrasive concentration, namely the number of abrasive particles played an important role in the removal of oxide film. When using the MAS, we could observe different removal mechanism of two-body and three-body abrasions according mixing ratio. The proper ratio to achieve high removal rate was 2 : 1 (D30 : D70) since most of the abrasives were active in material removal and carried out two-body abrasion.

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